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# Sediment Toxicity and the Distribution of Amphipods in Commencement Bay, Washington, USA

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# Sediment Toxicity and the Distribution of Amphipods in Commencement Bay, Washington, USA

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**The toxicity of 175 sediment samples from Commencement Bay, Washington, was measured by the survival of marine infaunal amphipods (*Rhepoxynius abronius*) during ten-day exposure to test sediment. Survival was high in sediment from offshore, deeper parts of the Bay, including two designated dredge material disposal sites. Within each of the major industrialized waterways there was a wide range in amphipod survival. Both acutely toxic and relatively nontoxic samples were collected from various areas within the Hylebos, Blair, Sitcum and City Waterways. Habitat differences, sedimentation rates, proximity to contaminant sources and sinks, and disruption of the seabed by prop scour and dredging could contribute to this variation in toxicity. Community structure data show a correlation between amphipod distribution and sediment toxicity, with lower amphipod density and species richness in the waterways than in the deeper part of the Bay. Phoxocephalid amphipods, a family that includes the bioassay species, were ubiquitous in the deeper Bay, but absent from the waterways. This correlation between laboratory and field results indicates the ecological relevance of the sediment bioassay.**

The Environmental Protection Agency has recently designated Commencement Bay, near Tacoma, Washington, USA (Fig. 1), as one of this nation's worst hazardous waste disposal areas. The concentration of synthetic organic compounds in water, suspended material, sediments and animal tissues is typically higher in the waterways of Commencement Bay than in other urban embayments of

**Fig. 1** Survival of the infaunal amphipod, *Rhepoxynius abronius*, in sediment from Commencement Bay. Twenty individuals were seeded in each sample.

Puget Sound (Malins *et al.*, 1980; Riley *et al.*, 1980). This chemical contamination is associated with increased frequencies of lesions in the liver and hepatopancreas of fishes and invertebrates (Malins *et al.*, 1980). Sediments less than 25 years old generally contain more organic contaminants than undisturbed older sediments (Riley *et al.*, 1981).

The waterways adjacent to the Bay serve many industrial activities associated with chemical manufacturing plants, a petroleum refinery, pulp mills, a naval depot, marinas, and other operations. The waterways continue to receive a variety of organic and inorganic toxic materials from industrial sources. For example, Riley *et al.* (1981) estimated current annual inputs to the Hylebos Waterway of 189 kg of chlorinated biphenyls, 0.06 kg of hexachlorobutadiene, 0.7 kg of benzanthracene and 0.6 kg of benz(a)pyrene. Material which is periodically dredged from the waterways historically has been dumped at two designated disposal sites in deeper parts of Commencement Bay, although to our knowledge only the deep site has been used in the past decade. Some dredged material also serves as landfill.

As part of a multidisciplinary study of benthic conditions in the deeper parts of Commencement Bay and adjacent waterways, we have examined spatial patterns in the structure of the macrobenthic community, sediment contamination by organic and inorganic compounds, and sediment toxicity as measured by the survival of marine amphipods during short-term exposure to sediments collected from the Bay and waterways. This report summarizes data on the degree and spatial extent of sediment toxicity and correlates the toxicity patterns with the distribution of amphipods, a faunal group that is particularly sensitive to sediment pollution (NMFS, 1972; Swartz *et al.*, 1979; Bellan-Santini, 1980).

## Materials and Methods

On four occasions in 1981 we tested the toxicity of a total of 175 sediment samples from Commencement Bay and its waterways (Figs 1–3). To provide maximum spatial coverage, most of the samples (125) were not replicated. However, on the second survey in May 1981, we collected five replicates at each of ten stations, five located along a transect between the two designated dredge material disposal sites in Commencement Bay, and one each on the north shore of Browns Point, and in the City, Sitcum, Blair and Hylebos Waterways.

In each of the four bioassays we included five sediment samples from lower Yaquina Bay, Oregon. The Yaquina Bay site supports a large natural population of the test species and provides an uncontaminated control or reference sediment for the benthic bioassay. The Yaquina Bay data were used as a control to statistically compare mean survival among the replicated samples in the second survey. The existence of statistically significant differences was first determined by analysis of variance. Dunnett's procedure was then used to compare the Commencement Bay means with the Yaquina Bay control (Steel & Torrie, 1960).

The benthic bioassay is an adaptation of the EPA/COE (1977) technique used to determine the toxicity of the solid phase of dredged material. We used only one test species, the infaunal amphipod, *Rhepoxynius abronius* (formerly identified as *Paraphoxus epistomus*), which is known to have a relatively high sensitivity to sediment contamination (Swartz *et al.*, 1979). A 2 cm deep layer of each test sediment was placed in a 1 l. beaker and covered with 800 ml of seawater (25 ppt, 15°C). Amphipods were collected from Yaquina Bay within four days of the initiation of the bioassay and randomly distributed among the beakers so that each received 20 individuals. Typically, the amphipods quickly swam to the bottom and buried in the sediment. Aeration was provided through 1.0 ml pipettes and the beakers were covered by watchglasses. Water was not replaced during the bioassay. After 10 days the contents of the beakers were sieved and survivors counted. Missing animals were assumed to have died and decomposed. This is a reasonable assumption, based on experiments which showed that the bodies of dead *R. abronius* begin to disintegrate within 3–4 days of their death. A complete description of this bioassay method will be published separately.

At subtidal sites sediment was collected with a modified 0.1 $m^2$ van Veen grab. Intertidal sediment was collected at low tide directly from the surface. Bioasssay samples were taken by core from the upper 2 cm sediment layer. During the first three surveys, samples were kept cold (4°C) until the bioassay was initiated within four days of sediment collection. Samples for the fourth bioassay were collected by staff from EPA Region X and the State of Washington Department of Ecology. These samples were frozen for a maximum of 11 weeks before the bioassay began.

After removing the bioassay sediment sample from the five replicate 0.1 $m^2$ grabs taken at ten stations in May 1981, the remainder of each sample was sieved through a 1.0 mm screen. Animals retained on the screen were preserved in 10% buffered formalin, and later transferred to 70% ETOH, identified to the species level and counted. To permit a comparison of faunal distributions with the amphipod toxicity data, we examined significant differences in mean amphipod density and number of species by analysis of variance and Student–Neuman–Keuls' multiple range test (Steel & Torrie, 1960). Data were transformed $[\ln(x+1)]$ prior to analysis.

## Results and Discussion

Results of the first two surveys showed that survival, relative to the Yaquina Bay controls, was high in the offshore, deeper portion of Commencement Bay and low in some parts of the waterways. Statistical analysis is appropriate for the second survey where five replicate samples were taken at ten stations and the Yaquina Bay control. Analysis of variance showed highly significant differences in the mean survival of *Rhepoxynius* at these stations ($F = 6.55^{***}$; $F_{0.001(10,44)} = 3.80$). Dunnett's procedure showed that survival was significantly different from the control in samples from the Hylebos lower turning basin (HI), the City Waterway opposite Slip No. 1 (CII) and Browns Points (B) (Table 1). There was no statistically significant difference in mean survival between the Yaquina Bay control, all five stations on the transect between the deep and shallow disposal sites in the deeper portion of Commencement Bay, and station SI in the Sitcum and LI in the Blair Waterways (Table 1). Mean survival in sediment from these stations did not vary greatly; between 17.0 and 18.2 of the 20 individuals survived.

**TABLE 1**

Mean survival of the infaunal amphipod, *Rhepoxynius abronius*, in sediment from Commencement Bay. Means are based on five replicate bioassays. Twenty individuals were seeded in each replicate. Means not connected by the vertical line are significantly less ($p < 0.05$) than the Yaquina Bay control.

| Location (station code) | Mean number of survivors |
|---|---|
| Yaquina Bay control (YB) | 18.2 |
| Sitcum Waterway (SI) | 17.8 |
| Bay Transect (DSIV) | 17.8 |
| Bay Transect (DSII) | 17.8 |
| Bay Transect (DSIII) | 17.6 |
| Shallow disposal site (DSV) | 17.2 |
| Deep disposal site (DSI) | 17.2 |
| Blair Waterway (LI) | 17.0 |
| Browns Point (B) | 15.2 |
| City Waterway (CII) | 14.2 |
| Hylebos Waterway (HI) | 12.2 |

The first two surveys showed that sediment in the central, deeper portion of Commencement Bay was not toxic, but that parts of the waterways, especially the Hylebos, may be contaminated with toxic materials at concentrations capable of causing acute mortality. Thus, collections for the third and fourth bioassays were concentrated in the waterways near potential sources or sites of contamination with an additional four intertidal samples taken from the north and south shores of the Bay. During the first two surveys, samples were almost always taken from mid-channel locations. In later collections we often sampled nearshore or intertidal sites.

Results from all four surveys are pooled in Table 2, which gives the frequency of survival in samples from Yaquina Bay, Commencement Bay, and the waterways. Two major patterns are evident. First, the frequency distribution supports the earlier conclusion that offshore Commencement Bay sediment is not acutely toxic to *Rhepoxynius* and is similar in this respect to Yaquina Bay sediment. Second, within each of the waterways and the nearshore area of Commencement Bay there is a tremendous range in survival. At some sites within each waterway most or all of the amphipods died; at other sites most or all survived.

Results of this study and Riley *et al.* (1981) show that no single site is representative of an entire waterway. Extrapolations from one sample to an entire waterway or comparisons between waterways based on single site analyses, such as the replicate sampling design of our second survey, can be misleading. The conclusion that stations SI in the Sitcum and LI in the Blair have low toxicity relative to stations CII in the City and HI in the Hylebos (Table 1) cannot be extrapolated to the waterways as a whole. The opposite conclusion might have been reached if a 'hot' spot had been sampled in the Blair or Sitcum.

With respect to sediment toxicity, these waterways are more similar than they are different. Each contains areas of both high and low sediment toxicity. Comparisons within waterways are more important than comparisons between waterways.

To depict the spatial distribution of sediment toxicity (Figs 1–3) we divided the frequency distributions of Table 2 into four classes: (1) 15–20 survivors, a level of relatively high survival within the typical control range; (2) 8–14, moderate survival, below the control range; (3) 1–7, low survival, well below controls; and (4) 0 survivors, very toxic conditions.

Within the deeper areas of Commencement Bay only one of 37 samples fell outside the control range (Fig. 1). Sediment was typically more toxic at the four intertidal sites sampled along the north and south shores of the Bay.

**TABLE 2**

Survival of the infaunal amphipod, *Rhepoxynius abronius*, in sediment from Commencement Bay, Washington, and Yaquina Bay, Oregon. Twenty amphipods were seeded in each sample.

| | Survival frequency | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Number of survivors | Yaquina Bay | Commencement Bay | | Hylebos Waterway | Blair Waterway | Sitcum Waterway | City Waterway | Other waterways |
| | | Offshore | Nearshore* | | | | | |
| 20 | 7 | 1 | | | | | 1 | |
| 19 | 8 | 9 | 1 | 2 | 4 | 1 | | |
| 18 | 1 | 12 | | 2 | 2 | 2 | 1 | 2 |
| 17 | 3 | 4 | | 3 | 4 | 3 | | 1 |
| 16 | | 4 | | 4 | 5 | | | |
| 15 | | 6 | 2 | 4 | 2 | 1 | 1 | |
| 14 | 1 | 1 | 2 | 2 | | 2 | 1 | 1 |
| 13 | | | 1 | 8 | 1 | | 1 | |
| 12 | | | | 4 | | 1 | | 1 |
| 11 | | | 1 | 7 | 1 | | 2 | |
| 10 | | | | 4 | 2 | | | 1 |
| 9 | | | | 3 | | | 1 | |
| 8 | | | | 4 | | 2 | | 1 |
| 7 | | | 1 | | | 1 | | |
| 6 | | | | | 2 | | 1 | |
| 5 | | | | 1 | 1 | | | |
| 4 | | | | 1 | | 1 | | |
| 3 | | | | 2 | | | | 1 |
| 2 | | | | 2 | 1 | 1 | | |
| 1 | | | 1 | 3 | | | | |
| 0 | | | | 10 | 2 | | 2 | 2 |
| Number of samples | 20 | 37 | 9 | 66 | 27 | 15 | 11 | 10 |
| Mean survival | 18.8 | 17.4 | 12.1 | 9.5 | 13.1 | 12.9 | 10.6 | 10.0 |

*Includes stations on the north and south shores of Commencement Bay and at Browns Point.

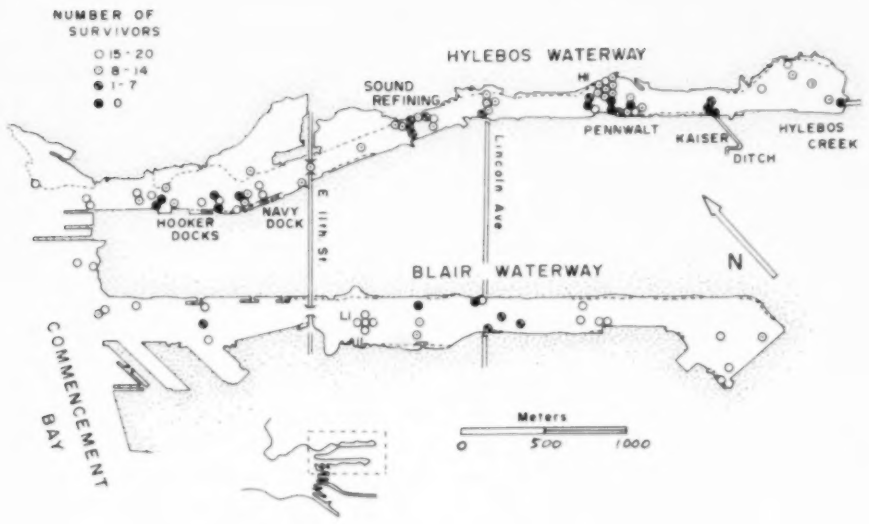


**Fig. 2** Survival of the infaunal amphipod, *Rhepoxynius abronius*, in sediment from the Hylebos and Blair Waterways adjacent to Commencement Bay. Twenty individuals were seeded in each sample.

In the Hylebos and Blair Waterways toxicity had a patchy distribution (Fig. 2). The large toxicity range was not associated with an obvious gradient, such as high levels in the upper portions reducing to low values near the entrance. Rather, the worst conditions in the Hylebos appear to be associated with potential stress sources such as the docks of manufacturing plants, drains and ditches. The most toxic conditions encountered in the Blair were in the central part of the waterway near Lincoln Ave.

Although fewer samples were collected in the other waterways, some spatial patterns are evident (Fig. 3). Very toxic sediments were collected in Slip No. 1 and at the upper end of the City Waterway. Survival was high at the entrances to the City and Middle Waterways. The three intertidal samples collected near the site of a pulp mill on the peninsula separating the Puyallup and St Paul Waterways were very toxic. Lowest survival in the Sitcum Waterway was for samples taken at nearshore or intertidal sites.

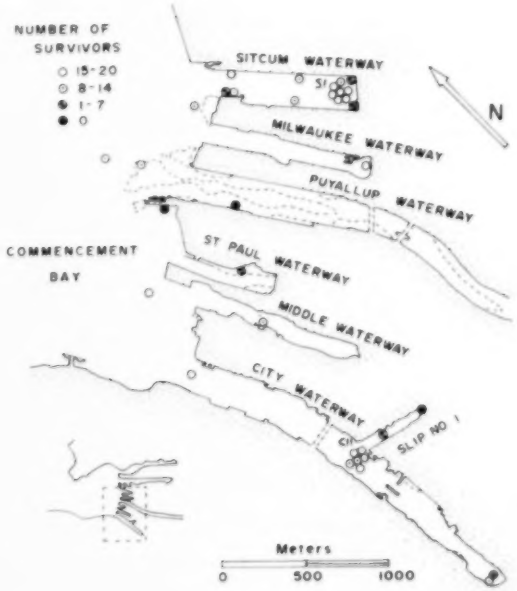


**Fig. 3** Survival of the infaunal amphipod, *Rhepoxynius abronius*, in sediment from waterways adjacent to Commencement Bay. Twenty individuals were seeded in each sample.

In all waterways, there was a patchy distribution of sediment toxicity. Several factors could account for this patchiness. Sediment contamination is often greatest in the immediate vicinity of point sources or sites of accumulation. Small scale changes in toxicity are evident in the distribution of highly toxic sediment samples between different habitats in the waterways (Table 3). When all samples from the waterways are combined, we collected 54 from mid-channel, 50 from nearshore subtidal, and 25 from intertidal sites. The percentage of samples with 8 or fewer survivors increased from 13% at mid-channel sites, to 30% nearshore subtidal, to 48% in the intertidal. These differences between habitats in the frequency of samples with high toxicity are statistically significant (Table 3). Intertidal and mid-channel sites are often separated by only a few decametres in the waterways. Thus, habitat differences, sedimentation rates, proximity to contaminant sources and sinks, and disruption of the seabed by prop scour and dredging could all contribute to the patchiness of sediment toxicity.

The benthic bioassay measures acute, lethal effects and may not be sensitive to chronic or sublethal impacts on biological communities. During the second survey we therefore took replicate biological samples at 10 stations for analysis of changes in benthic communities. Certain trends are evident in the distribution of amphipods (Table 4). Amphipods do not numerically dominate the benthos of Commencement Bay, but they were present at all stations except CII in City Waterway. Species richness and density of all amphipods were higher in deeper portions of the Bay and at Browns Point than in the waterways. Results of the multiple range test suggest a spatial gradient in which density and richness near the shallow disposal site (DSIV and DSV) are intermediate between depressed conditions in the

**TABLE 3**

Habitat distribution of samples with high toxicity (fewer than 8 of 20 amphipods survived) in the Commencement Bay waterways.

| Habitat | Number of samples: High toxicity | Number of samples: Total | Percent high toxicity |
|---|---|---|---|
| Mid-channel | 7 | 54 | 13.0 |
| Nearshore subtidal | 15 | 50 | 30.0 |
| Intertidal | 12 | 25 | 48.0 |
| Total | 34 | 129 | 26.4 |

$\chi^2 = 9.47^{**}$, $\chi^2_{[0.01]} = 9.21$

waterways and the more abundant amphipod assemblage near the deep disposal site. An average of only one amphipod species and 1.4 individuals were collected in each 0.1 $m^2$ grab from the waterways, whereas the corresponding averages for the three stations closest to the deep disposal site (DSI-III) were 5.8 species and 15.3 individuals.

Spatial changes in amphipod species composition were also evident, particularly in the family Phoxocephalidae to which our bioassay species belongs. Phoxocephalids are small (~5 mm, total length) infaunal organisms that burrow beneath the sediment surface without extending tubes or body parts into the overlying water. This intimate relation to the substrate together with their phylogenetic position may account for their relatively high sensitivity to sediment contamination. Word (1978) listed three phoxocephalid genera (*Rhepoxynius (=Paraphoxus), Metaphoxus* and *Heterophoxus*) as representative of control conditions for pollution gradients near large sewage outfalls in the Southern California Bight. Similarly, *Trichophoxus epistomus* is abundant in clean sands of the New York Bight but disappears near a sewage sludge dump site (NMFS, 1972; Swartz *et al.*, 1976).

Phoxocephalid amphipods were completely absent from the Commencement Bay waterways and Browns Point, but present at all five stations along the offshore Bay transect (Table 4). Within the transect phoxocephalids were least abundant at the shallow disposal site (DSV) closest to the waterways. We collected seven phoxocephalid species at the transect stations. *Rhepoxynius tridentatus* and *Heterophoxus oculatus* were most abundant. *Metaphoxus fultoni, Eobrolgus spinosus, Rhepoxynius variatus, R. bicuspidatus* and *R. abronius* (our bioassay species) were also present.

The absence of phoxocephalids at Browns Point may reflect that station's coarser substrate rather than chemical contamination. In laboratory choice experiments, *Rhepoxynius abronius* showed a preference for fine and very fine sand over medium and coarse sands (Swartz, unpublished data). At Browns Point 52.7% of the sediment was composed of medium sand or coarser particles. No more than 5.5% of the sediment at any other station fell into this size fraction. Amphipod richness and abundance are relatively high at Browns Point, but the species composition is quite different. The most abundant species, *Byblis veleronis* and *Ampelisca macrocephala,* were absent or rare in all other samples.

The amphipod fauna of the waterways is a remnant of the assemblage found elsewhere in Commencement Bay. Of the 34 species in our collection, none were restricted to the waterways and only eight species were found there. The most abundant species, *Hippomedon denticulatus,* was represented by only eight individuals in 20 0.1 $m^2$ grabs.

The distribution of amphipods is correlated with the general pattern of sediment toxicity in Commencement Bay. While certain patches of sediment in the waterways may not be toxic or contaminated, the structure of the amphipod assemblage reflects an overall level of stress. The absence of phoxocephalids and other taxa and the significant reduction in amphipod density suggest an integration of conditions in the waterways. However, the waterways are not devoid of macrobenthic life. Polychaetes and other taxa are very abundant. In future reports we will examine relations between sediment contamination and the condition of other segments of the benthic community.

**TABLE 4**

Distribution of amphipods in Commencement Bay and adjacent waterways. Density data are mean number of individuals (*N*) and species (*S*) per 0.1 $m^2$ grab*.

| Location (Station) | All amphipods: S | All amphipods: N | Phoxocephalid amphipods: S | Phoxocephalid amphipods: N | No. of samples |
|---|---|---|---|---|---|
| Commencement Bay transect | | | | | |
| Deep disposal site (DSI) | 6.4 | 15.4 | 1.2 | 3.0 | 5 |
| Transect station (DSII) | 5.4 | 12.0 | 2.4 | 6.2 | 5 |
| Transect station (DSIII) | 5.6 | 18.6 | 1.6 | 9.6 | 5 |
| Transect station (DSIV) | 2.8 | 6.2 | 0.8 | 2.2 | 4 |
| Shallow disposal site (DSV) | 2.2 | 3.0 | 0.5 | 0.8 | 4 |
| Browns Point (B) | 5.0 | 11.4 | 0 | 0 | 5 |
| Hylebos Waterway (HI) | 1.4 | 2.6 | 0 | 0 | 5 |
| Sitcum Waterway (SI) | 1.2 | 1.6 | 0 | 0 | 5 |
| Blair Waterway (LI) | 1.4 | 1.4 | 0 | 0 | 5 |
| City Waterway (CII) | 0 | 0 | 0 | 0 | 5 |

*There were significant differences between the 10 stations in mean *N* ($F = 19.35$, $p < 0.01$), and mean *S* ($F = 20.58$, $p < 0.01$) for all amphipods. The results of Student–Newman–Keuls' multiple range test are shown below, where any two means not underscored by the same line are significantly different ($p < 0.01$).

Number of species

| CII | SI | HI | LI | DSV | DSIV | B | DSII | DSIII | DSI |
|---|---|---|---|---|---|---|---|---|---|
| 0 | 1.2 | 1.4 | 1.4 | 2.2 | 2.8 | 5.0 | 5.4 | 5.6 | 6.4 |

Number of individuals

| CII | LI | SI | HI | DSV | DSIV | B | DSII | DSI | DSIII |
|---|---|---|---|---|---|---|---|---|---|
| 0 | 1.4 | 1.6 | 2.6 | 3.0 | 6.2 | 11.4 | 12.0 | 15.4 | 18.6 |

## Conclusions

1. Sediment from central Commencement Bay near and between the two designated disposal sites was not acutely toxic to the infaunal amphipod, *Rhepoxynius abronius.*

2. There was a great range in sediment toxicity within each of the major Commencement Bay waterways. Both highly toxic and nontoxic samples were collected from different parts of the Hylebos, Blair, Sitcum and City Waterways.

3. Sediment toxicity had a patchy distribution in the waterways. Habitat differences, sedimentation rates, proximity to contaminant sources and sinks, and disruption of the seabed by prop scour and dredging could contribute to this patchiness.

4. Our data show a correlation between amphipod distribution and sediment toxicity. Amphipod density and species richness are lower in the waterways than in the central Bay. Phoxocephalid amphipods are ubiquitous in the Bay, but absent from the waterways.

5. This correlation between laboratory and field results indicates the ecological relevance of the sediment bioassay.

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